EA−05 Light extraction efficiency of high refractive index glass substrate for OLED lighting

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OLED lighting is expected as a high efficiency lighting source. However, compared to the fluorescent lamp, the efficiency of commercial OLED lighting is not high. The main reason for the low efficiency of the OLED lighting is mismatch of refractive index between organic layers (nd=1.8-2.0) and glass (nd=1.52). High refractive-index glass substrate for OLED lighting named HX-1(nd=1.63) has been newly developed. The glass, made by over flow down draw process, has smooth surface and high chemical resistance required for OLED glass substrate. Light extraction efficiency of OLED lighting can be improved only by changing to HX-1 from common glass substrate.

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Introduction

OLED light is expected as a next generation high efficiency bendable lighting source. However, the efficiency of a commercial OLED lighting has not reached the fluorescent lamp. Standard structure of OLED shows in Figure 1.The main reasons for the low efficiency of the OLED lighting are reflections at each interface, which is caused by difference of refractive index between each layer. Because of the reflections, only about 25% of emitted light from organic layer is taken out to air. About 20% of the emitted light trapped in the glass substrate (substrate mode) and about 50% of the emitted light is trapped in the organic layers (waveguide mode) and electrode (evanescent mode). The various developments have been performed to increase the light which can be taken out in air.

Textured structure on the surface of glass substrate is well known as a technique to takes out the light trapped in glass. Generally, since incident angle of the ray of the light from the glass is larger than critical angle, the light is reflected at the interface and is impossible to be taken out light in air, but if there is texture structure at the interface of air and glass, the light can be taken out to air. Total reflection is ideally decreased by attaching a hemispherical lens to the air side of substrate, however, using large hemispherical lens on the OLED device is not practical. Alternatively, Micro Lens Array (MLA) and out-coupling film has been proposed as the technique to form the shape on the glass. They has been introduced to OLED lighting devices because of the simple process.

Next technique to improve the efficiency of the light emission is to reduce the mismatching of refractive index between organic material and glass substrate. Since the refractive index of organic materials are 1.8-2.0, the light, extracted into a glass substrate from the organic layer, increases by using the high refractive index glass (1.8-). However, conventional high refractive index glass (1.8-) reported so far has practical issues on productivity and chemical durability. Generally since optical glass have low viscosity in liquidus temperature, it is produced by casting method. It requires grindings and polishing process after slicing the glass block to supply the glass sheet.

HX-1 glass

High refractive index glass substrate HX-1 is developed. The glass can be produced by overflow down draw method which is famous for the mass-production process of the glass substrate for LCD. The refractive index of HX-1 is 1.63. Though the value is lower than that of ITO or organic materials, it is higher than commercially conventional available glass substrate. The higher refractive index of glass reduces the index mismatch of ITO and glass. That make it possible to extract more light from the organic layer into HX-1, consequently it realize the improvement of the efficiency of OLED device. Furthermore, HX-1 glass substrates have very high productivity in the overflow down draw process.

Light extraction efficiency

To investigate the relationship between the light extraction efficiency of the OLED and the refractive index of the glass substrate, two kinds of glass with different refractive index were prepared. The refractive index of two glass substrates are 1.63(HX-1), and 1.52(general refractive index glass). Generally the structure of a green phosphorescent OLED is shown in Figure 1, Glass / ITO, 100nm/HIL, 40nm/NPD, 50nm/Ir (ppy)$_3$ + CBP [6%], 30nm/BAlq, 10nm/Alq, 30nm/LiF, 0.8nm/Al, 150nm. This structure is used for the simulation.

As a result of optical simulation, the proportion of waveguide mode decreased from 11% to 5%, and the proportion of substrate mode increased from 21% to 28% by changing the glass substrate from general refractive index (nd1.52) glass to HX-1(nd1.63). Consequently, proportion of the external mode was almost the same. Namely, the light extraction efficiency was not improved. This is attributed to increasing the difference in refractive index between glass substrate and air.

On the other hand, when a hemisphere lens, which has the same refractive index with the glass substrate, is used at the air side of the glass substrate, the light extraction efficiency was improved from 44% to 50%. This is assumed that the light of substrate mode in the glass substrate was taken out to the air.

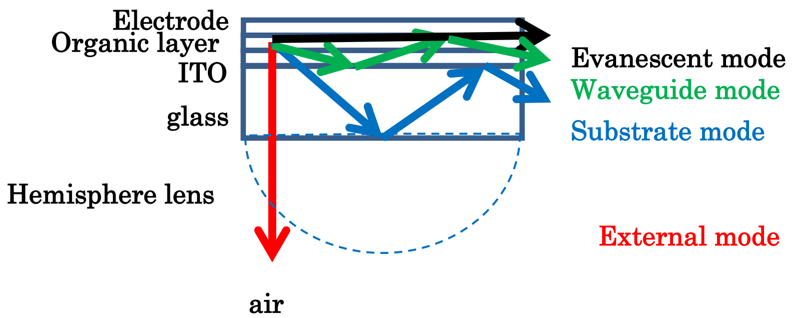

Figure 1. Standard OLED's structure and optical mode of OLED.

Table 1. Result of optical mode simulation.

	nd1.52		nd 1.63	
Hemisphere lens	without lens	with lens	without lens	with lens
Evanescent mode (electrode)	**45%**	**45%**	**45%**	**45%**
Waveguide mode (organic layer/ITO)	**11%**	**5%**	**5%**	**5%**
Substrate mode (glass)	**21%**	**44%**	**28%**	**50%**
External mode (air)	**23%**		**22%**	